

**Consequences of a  $\Lambda_c/D$  enhancement effect on the non-photonic  
electron nuclear modification factor in central heavy ion collisions  
at RHIC energy**

G. Martínez-García<sup>1\*</sup>, S. Gadrat<sup>1†</sup> and P. Crochet<sup>2‡</sup>

<sup>1</sup>*SUBATECH (IN2P3/CNRS - Ecole des Mines - Université de Nantes) Nantes, France*

<sup>2</sup>*Laboratoire de Physique Corpusculaire (IN2P3/CNRS - Université Blaise Pascal)*

*Clermont-Ferrand, France*

(February 2, 2008)

**Abstract**

The RHIC experiments have measured the nuclear modification factor  $R_{AA}$  of non-photonic electrons in Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV. This  $R_{AA}$  exhibits a large suppression for  $p_t > 2$  GeV/ $c$  which is commonly attributed to heavy-quark energy loss. It is expected that the heavy-quark radiative energy loss is smaller than the light quark one because of the so-called dead-cone effect. An enhancement of the charm baryon yield with respect to the charm meson yield, as it is observed for light and strange hadrons, can explain part of the suppression. This phenomenon has been put forward in a previous work. We present in this paper a more complete study based on a detailed simulation which includes electrons from charm and bottom decay, charm and bottom quark realistic energy loss as well as a more realistic modeling of the

---

\*Gines.Martinez@subatech.in2p3.fr

†Sebastien.Gadrat@subatech.in2p3.fr

‡Philippe.Crochet@clermont.in2p3.fr

$\Lambda_c/D$  enhancement. We show that a  $\Lambda_c/D$  ratio close to unity, as observed for light and strange quarks, could explain 20–25% of the suppression of non-photonic electrons in central Au+Au collisions. This effect remains significant at relatively high non-photonic electron transverse momenta of 8–9 GeV/ $c$ .

One of the most robust experimental evidence for the creation of a new state of matter in heavy ion collisions at the Relativistic Heavy Ion Collider (RHIC) is the large suppression of light hadrons at high transverse momentum ( $p_t$ ) [1]. This phenomenon is well reproduced by models which take into account the radiative energy loss of high  $p_t$  light quarks and gluons propagating through a dense medium of colored quarks and gluons [2]. Further insights into the underlying mechanism can be obtained from the study of heavy hadrons. In contrast to intermediate- $p_t$  light hadrons which are predominantly produced by gluon fragmentation, charm and bottom hadrons originate from the fragmentation of heavy quarks. Quarks are supposed to lose less energy than gluons in the medium due to a smaller color charge coupling. In addition, radiative energy loss was predicted to be smaller for heavy quarks as compared to light quarks because of the so-called “dead-cone” effect which limits the medium induced radiative energy loss at forward angles [3]. Surprisingly, recent data from the PHENIX and the STAR collaborations in Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV show that the quenching of heavy quarks, as studied indirectly via the so-called non-photonic electrons<sup>1</sup>, is stronger than theoretical expectations [4–6] and is as large as that of light mesons. Reconciling these data with model predictions is a real challenge which triggers a lot of theoretical activities nowadays. Only models which assume a very large medium opacity [7], an additional collisional energy loss [8] or effective energy loss from multiple

---

<sup>1</sup>In contrast to light hadrons, the heavy flavor quenching is, so far, not measured experimentally through identified hadrons, but in an inclusive way via the nuclear modification factor ( $R_{AA}$ ) of non-photonic electrons. The latter is obtained from the  $p_t$  distributions of electrons (after subtraction of Dalitz-decay electrons from light hadrons and photon-conversion electrons) in  $AA$  collisions ( $dN_{AA}^e/dp_t$ ) and in  $pp$  collisions ( $dN_{pp}^e/dp_t$ ) as:

$$R_{AA} = \frac{dN_{AA}^e/dp_t}{\langle N_{coll}^{AA} \rangle dN_{pp}^e/dp_t}$$

where  $\langle N_{coll}^{AA} \rangle$  is the average number of nucleon-nucleon collisions corresponding to a given centrality class.

fragmentations and dissociations of heavy quarks and mesons ( $D$  and  $B$ ) in the medium [9] can describe, with a relatively good agreement, the data (for a recent review, see [10]).

In this paper we investigate the possibility that part of the strong suppression of non-photonic electrons might be due to another source of electrons, namely charmed baryons. Indeed, whereas light mesons are largely suppressed in heavy ion collisions at RHIC, the suppression of non-strange and strange baryons is observed to be much less in the intermediate  $p_t$  range ( $2 < p_t < 4$  GeV/ $c$ ) [11]. This is commonly referred to as the anomalous baryon/meson enhancement. This anomalous baryon/meson enhancement is relatively well understood in the framework of the recombination model which assumes that, at low and intermediate  $p_t$ , hadronization occurs via the coalescence of “free” quarks (and anti-quarks) [12]. An anomalous baryon/meson enhancement for charm hadrons leads naturally to a non-photonic electron  $R_{AA}$  smaller than one. This is mostly due to a smaller semi-leptonic decay branching ratio of charm baryons ( $\Lambda_c$ ) as compared to charm mesons (see Tab. I). As a consequence, part of the experimentally measured  $R_{AA}$  of non-photonic electrons should not be attributed to energy loss. We show that the  $\Lambda_c/D$  enhancement can explain up to 25% of the non-photonic electron suppression data measured by the PHENIX collaboration in Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV [13].

The main assumption we put forward is that, in a deconfined medium, charm baryon production is enhanced relative to charm meson production, as compared to the vacuum. This assumption is qualitatively justified in the framework of the recombination model. Although this model does not provide detailed predictions on charm hadron production yet, it successfully describes the (non-charm) baryon/meson enhancement measured in Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV. A relatively good agreement is obtained not only for the light hadron ratio  $p/\pi^+$ , but also for heavier hadron ratios such as  $\Lambda/K_s^0$  and  $\Omega/\phi$  [14]. Extrapolating these results to charm hadrons is not straightforward because the mass of the charm quark is much larger than that of light and strange quarks. The consequences are threefold as far as the recombination mechanism is concerned. First, whereas the  $p_t$  of a light baryon (meson) amounts to 3 (2) times the initial  $p_t$  of its valence quarks, the

$p_t$  of a (single) charm baryon or a charm meson is likely to be very close to that of the charm quark. Secondly, considering a light quark and a heavy quark with the same velocity (which is the essential requirement for the coalescence process to take place [15]), the heavy quark momentum is much larger than that of light partons. As a consequence, one can expect the enhancement of the charm baryon/meson ratio to appear at higher  $p_t$  than that of non-charm hadrons. The recombination model indeed predicts, for non-strange and strange hadrons, that the heavier the hadron, the larger the  $p_t$  of the baryon/meson enhancement. This has been observed for non-strange and strange baryon/meson ratios by the STAR collaboration [14]. Finally, the fragmentation time of heavy quarks is small as compared to light quarks. According to [9], the formation time of a 10 GeV/ $c$  pion,  $D$  meson and  $B$  meson is 20, 1.5 and 0.4 fm/ $c$ , respectively and it is as small as  $\sim 3$  fm/ $c$  for a  $\Lambda_c$  with  $p_t = 20 - 30$  GeV/ $c$ . Due to these considerations, it is obvious that the baryon/meson enhancement for non-charm hadrons and charm hadrons can be significantly different. In the following, we only assume that, in view of experimental results on the baryon/meson enhancement for non-strange and strange hadrons, a similar enhancement is a priori conceivable for charm hadrons<sup>2</sup>. Remarkably, such an enhancement has strong implications on the nuclear modification factor of non-photonic electrons. It leads to a decrease of the yield of non-photonic electrons in  $A + A$  collisions because, as shown in Tab. I, the inclusive semi-leptonic decay branching ratio of charm baryons is smaller than that of charm mesons. Therefore, the nuclear modification factor of non-photonic electrons should decrease as well. This can be easily illustrated in the following way. Assuming that charm production scales with the number of binary collisions (i.e.  $R_{AA} = 1$  in absence of medium effects) and that the relative yields of  $D$  mesons are the same in  $pp$  and in  $A + A$  collisions, a  $p_t$  integrated  $R_{AA}$  can be calculated for different  $\mathcal{C}$  enhancement factors,

---

<sup>2</sup>A very recent theoretical study in the framework of the recombination model confirms this assumption [16].

$$\mathcal{C} = \left( N_{\Lambda_c, \bar{\Lambda}_c} / N_D \right)_{AA} / \left( N_{\Lambda_c, \bar{\Lambda}_c} / N_D \right)_{pp}$$

with

$$N_{\Lambda_c, \bar{\Lambda}_c} / N_D = \frac{N_{\Lambda_c} + N_{\bar{\Lambda}_c}}{N_{D^+} + N_{D^-} + N_{D^0} + N_{\bar{D}^0} + N_{D_s^+} + N_{D_s^-}} \quad (1)$$

according to

$$R_{AA} = \frac{1 + (N_{\Lambda_c, \bar{\Lambda}_c} / N_D)_{pp}}{1 + \mathcal{C}(N_{\Lambda_c, \bar{\Lambda}_c} / N_D)_{pp}} \times \frac{1 + \mathcal{C}(N_{e \leftarrow \Lambda_c} / N_{e \leftarrow D})_{pp}}{1 + (N_{e \leftarrow \Lambda_c} / N_{e \leftarrow D})_{pp}} \quad (2)$$

where

$$N_{e \leftarrow \Lambda_c} / N_{e \leftarrow D} = \frac{(N_{\Lambda_c, \bar{\Lambda}_c} / N_D) BR_{\Lambda_c, \bar{\Lambda}_c}}{(N_{D^\pm} / N_D) BR_{D^\pm} + (N_{D^0, \bar{D}^0} / N_D) BR_{D^0, \bar{D}^0} + (N_{D_s^\pm} / N_D) BR_{D_s^\pm}}. \quad (3)$$

$N$  is the charm hadron yield and  $BR$  is the hadron semi-leptonic decay branching ratio. According to Tab. I,  $N_{\Lambda_c, \bar{\Lambda}_c} / N_D = 7.3\%$ ,  $N_{D^\pm} / N_D = 21\%$ ,  $N_{D^0, \bar{D}^0} / N_D = 67\%$ , and  $N_{D_s^\pm} / N_D = 12\%$  such that  $N_{e \leftarrow \Lambda_c} / N_{e \leftarrow D} = 3.63\%$ . Therefore, an enhancement factor  $\mathcal{C}$  of 12 leads to a non-photonic electron  $R_{AA}$  of  $0.79 \pm 0.07$  and in the extreme case of an infinite enhancement, the non-photonic electron  $R_{AA}$  reaches 0.51.

The above idea has already been proposed in [17]. Before going to our simulation results, we present in Tab. II the main differences between our approach and the one of ref. [17]. The choice of a Gaussian shape for the  $p_t$  dependence of the  $\Lambda_c/D$  ratio in Au+Au collisions is motivated by results from the coalescence model for heavy quarks [19]. For  $pp$  collisions, we use the predictions from PYTHIA and not the shape from the measured  $\Lambda/K_s^0$  ratio since experimental results from the STAR collaboration indicate a strong mass dependence of baryon/meson ratios [14]. These assumptions lead to a significant difference in the maximum the  $\Lambda_c/D$  ratio and in its location in  $p_t$ , as it is reported later. Finally, the present work includes a more realistic treatment of the heavy-quark energy loss as well as the contribution of electrons from bottom decay which is ignored in [17].

Our simulation framework is based on the PYTHIA-6.152 event generator [20]. The PYTHIA input parameters were first tuned according to [21] and the PHENIX acceptance cut ( $|\eta| < 0.35$ ) was applied in order to correctly reproduce the  $p_t$  distribution of non-photonic electrons measured in  $pp$  collisions at  $\sqrt{s} = 200$  GeV [13]. As it can be seen in

Fig. 1, the agreement between the simulation and the data is rather good except in the high  $p_t$  region where the simulation under-predicts the data. The result of the simulation is also compared to FONLL (Fixed Order Next to Leading Log) predictions [22]. As already observed in [13], the PHENIX data is in agreement with FONLL within the theoretical uncertainties.

Table I shows that the  $\Lambda_c/D$  ratio amounts to 7.3% (in  $4\pi$ ) which translates to 3.63% after convolution of the species yields with their corresponding semi-leptonic decay branching ratio. On the other hand, Fig. 2 shows that, in the  $p_t > 2$  GeV/ $c$  region of interest discussed hereafter, this ratio is even smaller ( $\sim 1.5\%$ ) because the decay electron spectrum of  $\Lambda_c$  is softer than that of  $D$  mesons. This leads to an additional suppression of the non-photonic electron yield at intermediate  $p_t$ .

As stated above, the non-photonic electron  $p_t$  distribution in Au+Au collisions has been evaluated after considering an enhancement whose shape is, according to the predictions of the coalescence model [19], assumed to be a Gaussian versus  $p_t$ . It has the following parameters. Mean: 5 GeV/ $c$ , constant:  $\sim 0.9$  and sigma: 2.9 GeV/ $c$ . The constant of 0.9 is obtained from  $N_{\Lambda_c, \bar{\Lambda}_c}/N_D \times \mathcal{C}$  with  $N_{\Lambda_c, \bar{\Lambda}_c}/N_D = 7.3\%$  (Tab. I) and  $\mathcal{C} = 12$ . Such an enhancement factor  $\mathcal{C} = 12$  is justified since the resulting  $\Lambda_c/D$  ratio of  $\sim 0.9$  is of the same order of magnitude as the non-strange and strange baryon/meson ratios measured by the STAR collaboration [14]. In contrast, the corresponding (enhanced)  $\Lambda_c/D$  ratio is in ref. [17] located at lower  $p_t$  and its maximum is close to 1.7. The enhancement is applied such that the  $p_t$ -differential charm cross-section is conserved. The latter is an arbitrary choice that could be justified since most of the charm hadron transverse momentum is given by the charm quark whatever, baryon or meson, this hadron is. We finally compute the  $R_{AA}$  ratio from the non-photonic electron  $p_t$  spectra assuming that the only medium induced effect is the  $\Lambda_c/D$  enhancement. The results are shown in Fig. 3 together with the PHENIX data. Note that at this step only electrons from charm decay are considered and heavy-quark energy loss is neglected. The simulated  $R_{AA}$  ratio is shown only for  $p_t > 2$  GeV/ $c$  since shadowing might play a role and has not been considered in the simulation. One can see

that the  $\Lambda_c/D$  ratio close to unity in central collisions at  $p_t = 5$  GeV/ $c$  can already explain  $\sim 40\%$  of the suppression of non-photonic electrons in the  $2 - 4$  GeV/ $c$   $p_t$  range. Even in the high  $p_t$  region ( $8 - 9$  GeV/ $c$ ) the  $\Lambda_c/D$  enhancement results in a significant suppression of non-photonic electrons.

In the next step  $c$  quark radiative and collisional energy loss is included in the simulation. This is achieved by a convolution of our non-photonic electron  $p_t$  spectra with the differential suppression factors taken from [23]. It is shown in Fig. 4 that the relative suppression originating from the  $\Lambda_c/D$  enhancement is about the same amplitude than the one from the charm collisional energy loss and represents about 36(20)% of the observed suppression at  $p_t = 4(9)$  GeV/ $c$ . In contrast, the suppression reported in [17] is less than 20% in the  $p_t$  range  $2 - 5$  GeV/ $c$  and becomes negligible for  $p_t > 5$  GeV/ $c$ .

Finally the bottom contribution is added in the simulation. This obviously reduces the suppression of the sum of non-photonic electrons because  $b$  quarks are supposed to lose less energy than  $c$  quarks. However, the relative contribution of  $c$  and  $b$  quarks to the total non-photonic electron yield is not well known. According to FONLL predictions, the crossing point ( $p_t^{cp}$ ) between charm and bottom electron decay  $p_t$  spectra is expected to be located in the range  $2.5 < p_t < 10.5$  GeV/ $c$ . Therefore we have considered two scenarios to include the bottom contribution: a crossing point in the central value predicted by FONLL ( $p_t^{cp} = 4.5$  GeV/ $c$ ) and the highest possible crossing point allowed by the calculation ( $p_t^{cp} = 10.5$  GeV/ $c$ ). The latter results in the weakest contribution of electrons from  $b$  quark decay to the total non-photonic electron yield. As shown in Fig. 5, whatever the assumed crossing point, the effect of the  $\Lambda_c/D$  enhancement remains visible. It leads to a decrease of the non-photonic electron  $R_{AA}$  of about 10(25)% for a crossing point at  $p_t^{cp} = 4.5(10.5)$  GeV/ $c$ .

In addition to the  $\Lambda_c/D$  enhancement addressed in this work, one could expect an enhancement of the  $D_s/D$  ratio due to the strangeness enhancement in heavy ion collisions. According to Tab. I, the  $D_s^\pm$  semi-leptonic decay branching ratio is similar to that of  $D^0$  which represents the main source of non-photonic electrons. An enhancement of  $D_s^\pm$  mesons would therefore not affect significantly the  $R_{AA}$  of non-photonic electrons. However, as



the uncertainty on the measured semi-leptonic decay branching ratio of  $D_s^\pm$  mesons is large (Tab. I), the contribution of  $D_s^\pm$  mesons to the non-photonic electron yield and consequently to the non-photonic electron  $R_{AA}$  cannot be estimated precisely. From the theoretical side, according to the Spectator Model for charm mesons decay, the semi-leptonic decay widths for the different charm mesons should be equivalent [24]. Knowing charm meson lifetimes [18] and branching ratios for  $D^0$  and  $D^\pm$  (see Tab.I), one can estimate the  $D_s^\pm$  branching ratio to  $8.2 \pm 0.2\%$  which appears to be consistent with the measured value.

In summary, we have shown that an enhancement of the  $\Lambda_c/D$  ratio in heavy ion collisions has important consequences on the nuclear modification factor of non-photonic electrons. Such an enhancement, which has recently been predicted by the coalescence model and which has already been measured for non-strange and strange hadrons, would significantly reduce the  $R_{AA}$  of non-photonic electrons at intermediate  $p_t$ . This is a consequence of the smaller semi-leptonic decay branching ratio of charm baryons compared to that of charm mesons and of the softer decay lepton spectrum from charm baryons compared to that of charm mesons. In the most realistic situation investigated in the present work the enhancement leads to an additional non-photonic electron suppression of  $10 - 25\%$  (with respect to the suppression observed without charm baryon/meson enhancement). This suppression can even be larger in case of a weaker bottom contribution to the non-photonic electron spectrum. We conclude that it is therefore premature to interpret the non-photonic electron  $R_{AA}$  data before a possible enhancement of the  $\Lambda_c/D$  ratio is measured experimentally. Heavy quark energy loss can be studied in a much cleaner way via the nuclear modification factor of exclusively reconstructed charm hadrons. Such measurements should be possible with the RHIC-II experiments [25] and with the ALICE experiment at the LHC [26]. We finally note that the  $\Lambda_c/D$  enhancement can possibly influence the elliptic flow of non-photonic electrons as well.

## ACKNOWLEDGMENTS

We gratefully acknowledge Anton Andronic, Pol-Bernard Gossiaux and Peter Levai for carefully reading the manuscript and for valuable suggestions and Stéphane Peigné and Vincenzo Greco for fruitful discussions.

## REFERENCES

- [1] see e.g. J. Adams *et al.* [STAR Collaboration], Phys. Rev. Lett. **91**, (2003) 172302 [arXiv:nucl-ex/0305015]; C. Adler *et al.* [STAR Collaboration], Phys. Rev. Lett. **89**, (2002) 202301 [arXiv:nucl-ex/0206011]; S. S. Adler *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **91** (2003) 072301 [arXiv:nucl-ex/0304022]; K. Adcox *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **88** (2002) 192303 [arXiv:nucl-ex/0202002]; I. Arsene [BRAHMS Collaboration], [arXiv:nucl-ex/0610021]; B. Alver *et al.* [PHOBOS Collaboration], Phys. Rev. Lett. **96**, (2006) 212301 [arXiv:nucl-ex/0512016].
- [2] For reviews, see e.g. C. A. Salgado, Nucl. Phys. A **774**, 267 (2006) [arXiv:hep-ph/0510062]; X. N. Wang, Nucl. Phys. A **774**, 215 (2006) [arXiv:nucl-th/0511001] and references therein.
- [3] Y. L. Dokshitzer and D. E. Kharzeev, Phys. Lett. B **519**, 199 (2001) [arXiv:hep-ph/0106202].
- [4] S. S. Adler *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **96**, (2006) 032301 [arXiv:nucl-ex/0510047];
- [5] A. Adare *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **98**, (2007) 172301 [arXiv:nucl-ex/0611018].
- [6] B. I. Abelev *et al.* [STAR Collaboration], Phys. Rev. Lett. **98**, (2007) 192301 [arXiv:nucl-ex/0607012].
- [7] N. Armesto, M. Cacciari, A. Dainese, C. A. Salgado and U. A. Wiedemann, Phys. Lett. B **637**, 362 (2006) [arXiv:hep-ph/0511257].
- [8] M. Djordjevic, J. Phys. G **32**, S333 (2006) [arXiv:nucl-th/0610054]; H. van Hees, V. Greco and R. Rapp, Phys. Rev. C **73**, 034913 (2006) [arXiv:nucl-th/0508055].
- [9] A. Adil and I. Vitev, Phys. Lett. B **649**, 139 (2007) [arXiv:hep-ph/0611109].

- [10] R. Averbeck, proceedings of Quark Matter 2006, 19th Conference on Ultra-Relativistic Nucleus-Nucleus Collisions, Shanghai, November 14-20, 2006, J. Phys. G. **34**, S567 (2007).
- [11] see e.g. B. I. Abelev *et al.* [STAR Collaboration], Phys. Rev. Lett. **97**, (2006) 152301 [arXiv:nucl-ex/0606003]; J. Adams *et al.* [STAR Collaborations], [arXiv:nucl-ex/0601042]; S. S. Adler *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **91**, (2003) 172301 [arXiv:nucl-ex/0305036]; S. S. Adler *et al.* [PHENIX Collaboration], Phys. Rev. C **69**, 034909 (2004) [arXiv:nucl-ex/0307022]; I. Arsene *et al.* [BRAHMS Collaboration], Phys. Rev. C **72**, 014908 (2005) [arXiv:nucl-ex/0503010].
- [12] R. J. Fries, B. Muller, C. Nonaka and S. A. Bass, Phys. Rev. Lett. **90**, (2003) 202303 [arXiv:nucl-th/0301087]; R. J. Fries, B. Muller, C. Nonaka and S. A. Bass, Phys. Rev. C **68**, 044902 (2003) [arXiv:nucl-th/0306027]; V. Greco, C. M. Ko and P. Levai, Phys. Rev. Lett. **90**, (2003) 202302 [arXiv:nucl-th/0301093]; V. Greco, C. M. Ko and P. Levai, Phys. Rev. C **68**, 034904 (2003) [arXiv:nucl-th/0305024]; R. C. Hwa and C. B. Yang, Phys. Rev. C **70**, 024904 (2004) [arXiv:hep-ph/0312271]; R. C. Hwa and C. B. Yang, Phys. Rev. C **67**, 034902 (2003) [arXiv:nucl-th/0211010].
- [13] A. Adare *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **97**, (2006) 252002 [arXiv:hep-ex/0609010].
- [14] S. Blyth, proceedings of Quark Matter 2006, 19th Conference on Ultra-Relativistic Nucleus-Nucleus Collisions, Shanghai, November 14-20, 2006, J. Phys. G **34**, S933 (2007).
- [15] Z. W. Lin and D. Molnar, Phys. Rev. C **68**, 044901 (2003) [arXiv:nucl-th/0304045].
- [16] S. H. Lee, K. Ohnishi, S. Yasui, I. K. Yoo and C. M. Ko, arXiv:0709.3637 [nucl-th].
- [17] P. R. Sorensen and X. Dong, Phys. Rev. C **74** (2006) 024902 [arXiv:nucl-th/0512042]; P. Sorensen, J. Phys. G **32** (2006) S135 [arXiv:nucl-ex/0701048]; P. Sorensen, Eur. Phys.

- J. C **49** (2007) 379.
- [18] W. M. Yao *et al.* [Particle Data Group], J. Phys. G **33**, 1 (2006).
- [19] V. Greco, Quenching Day, INFN, 2005, see  
<http://alice.pd.infn.it/quenchingDay.html>.
- [20] T. Sjöstrand, Comput. Phys. Commun. **82**, 74 (1994).
- [21] K. Adcox *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **88**, (2002) 192303  
[arXiv:nucl-ex/0202002].
- [22] M. Cacciari, P. Nason and R. Vogt, Phys. Rev. Lett. **95** (2005) 122001 [arXiv:hep-ph/0502203].
- [23] S. Wicks, W. Horowitz, M. Djordjevic and M. Gyulassy, Nucl. Phys. A **784** (2007) 426  
[arXiv:nucl-th/0512076].
- [24] G. Altarelli, N. Cabibbo, G. Corbo, L. Maiani and G. Martinelli, Nucl. Phys. B **208**  
(1982) 365.
- [25] B. Jacak, proceedings of Quark Matter 2006, 19th Conference on Ultra-Relativistic  
Nucleus-Nucleus Collisions, Shanghai, November 14-20, 2006, J. Phys. G. **34**, S543  
(2007).
- [26] B. Alessandro *et al.* [ALICE Collaboration], J. Phys. G **32**, 1295 (2006).

# TABLES

TABLE I. Inclusive decay branching ratio ( $BR$ ) of charm hadrons into  $e + \text{anything}$  [18] and yield ( $N$ ) of charm hadrons (in  $4\pi$ ) in  $pp$  collisions at  $\sqrt{s} = 200$  GeV from the present PYTHIA simulation using input parameters as described in [21]. The total cross-section for charm production is normalized to the experimental value obtained in [21].  $N_{\Lambda_c}$  and  $N_{\bar{\Lambda}_c}$  include primarily produced  $\Lambda_c$  and  $\bar{\Lambda}_c$  as well as those from  $\Sigma_c$  and  $\bar{\Sigma}_c$  decay.  $\epsilon_{N_e}(BR)$  is the contribution to the uncertainty of the total electron yield due to the uncertainty on the particle  $BR$ .

| Hadron                   | $D^+$          | $D^-$ | $D^0$           | $\bar{D}^0$ | $D_s^+$       | $D_s^-$ | $\Lambda_c$   | $\bar{\Lambda}_c$ |
|--------------------------|----------------|-------|-----------------|-------------|---------------|---------|---------------|-------------------|
| $BR$ (%)                 | $17.2 \pm 1.9$ |       | $6.71 \pm 0.29$ |             | $8_{-5}^{+6}$ |         | $4.5 \pm 1.7$ |                   |
| $N$ ( $\times 10^{-3}$ ) | 3.00           | 3.07  | 9.31            | 9.85        | 1.82          | 1.60    | 1.23          | 0.85              |
| $\epsilon_{N_e}(BR)$ (%) | 1.08           | 1.10  | 1.31            | 1.39        | 4.41          | 3.58    | 1.51          | 1.04              |

TABLE II. Main differences between the approach presented in [17] and this work. See text for more details.

|  | [17]                                     | this work                                |
|--|--|--|
| $\Lambda_c/D$ versus $p_t$ in Au+Au collisions | as $\Lambda/K_s^0$ data                  | Gaussian                                 |
| $\Lambda_c/D$ versus $p_t$ in $pp$ collisions  | as $\Lambda/K_s^0$ data                  | PYTHIA                                   |
| Maximum of the $\Lambda_c/D$ enhancement       | $\sim 1.7$ at $p_t \sim 3 \text{ GeV}/c$ | $\sim 0.9$ at $p_t \sim 5 \text{ GeV}/c$ |
| Energy loss                                    | hadron shape scaling                     | [23]                                     |
| Electrons from bottom decay                    | no                                       | yes                                      |

# FIGURES

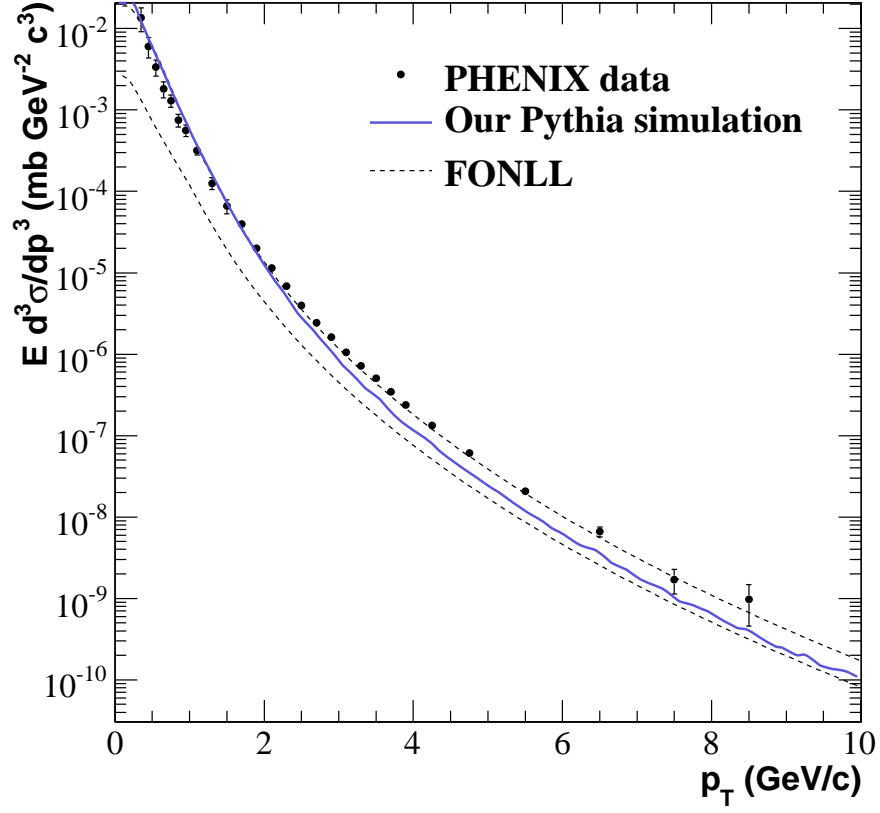


FIG. 1. Invariant differential cross-section of non-photonic electrons (dots) measured in  $pp$  collisions at  $\sqrt{s} = 200$  GeV [13]. The dashed curves show the prediction from FONLL calculations [22]. The solid curve shows the result of the PYTHIA simulation as described in the text. The simulated spectrum is normalized from the integration of the measured spectrum in the range  $1.4 < p_t < 4$  GeV/ $c$ .



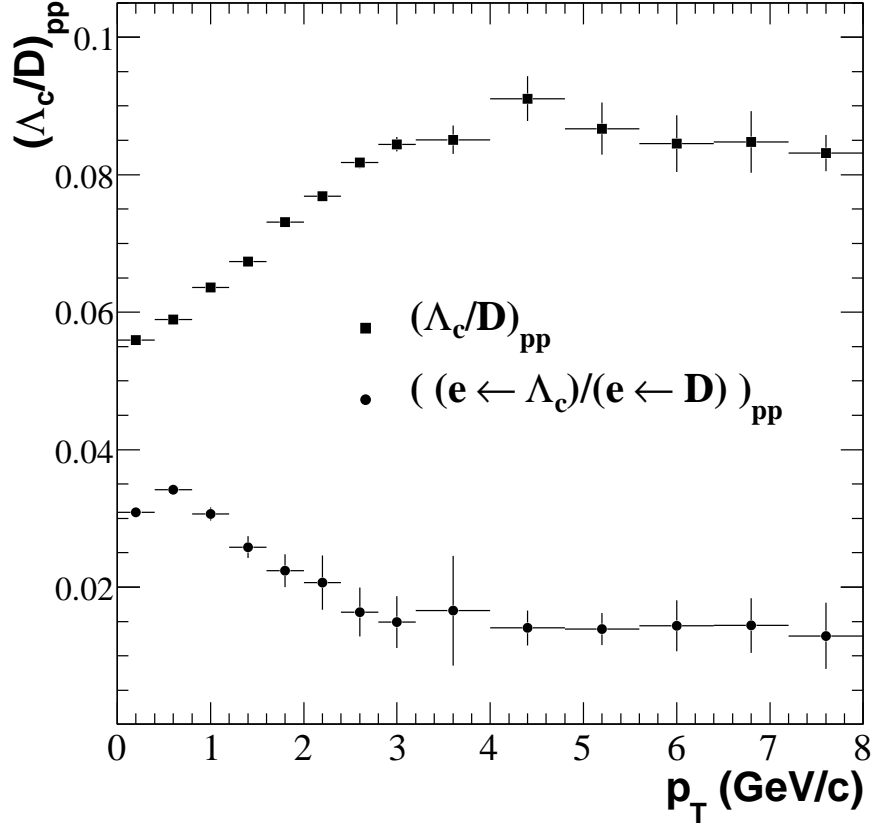


FIG. 2. Transverse momentum dependence of the charm baryon/meson ratio (squares) and decay electrons from charm baryons over decay electrons from charm mesons (dots). The results are obtained from the PYTHIA simulation described in the text for  $pp$  collisions at  $\sqrt{s} = 200$  GeV.

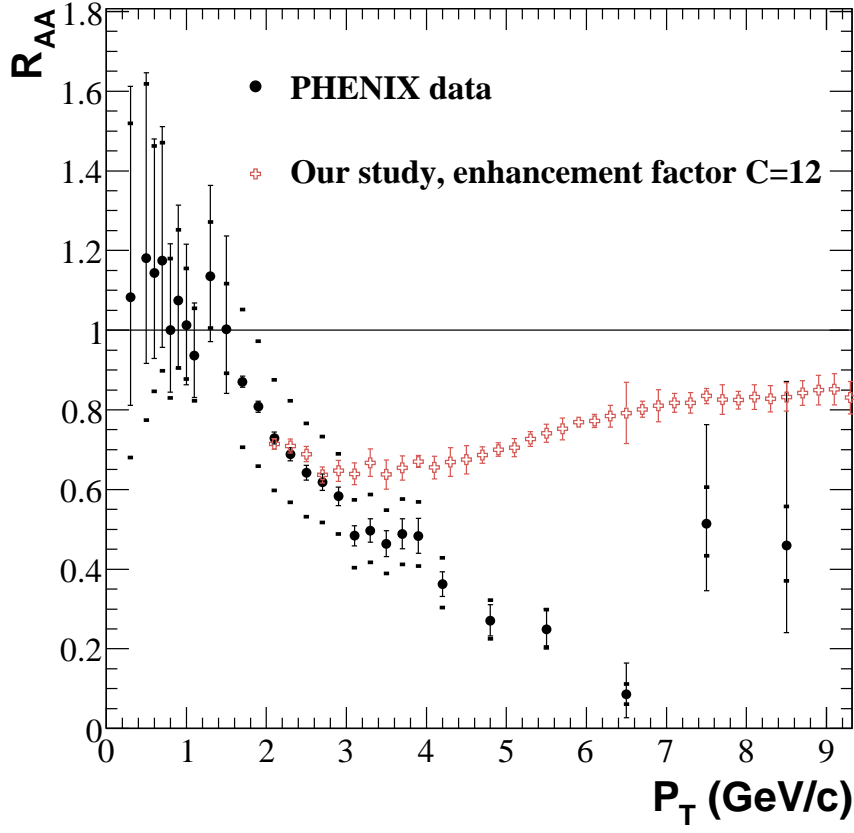


FIG. 3. Nuclear modification factor of non-photonic electrons (dots) measured in central (0 – 10%) Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV [5]. The crosses correspond to the results of the simulation described in the text for a  $\Lambda_c/D$  enhancement factor of 12.

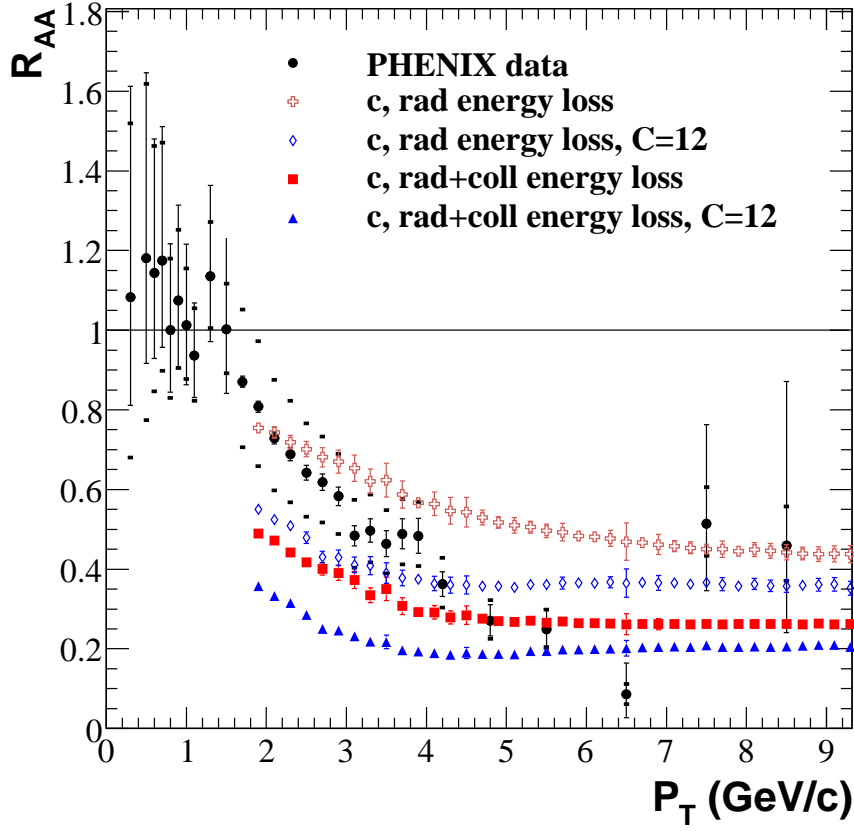


FIG. 4. Nuclear modification factor of non-photonic electrons (dots) measured in central (0–10%) Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV [5]. The symbols show the result of the simulation described in the text.

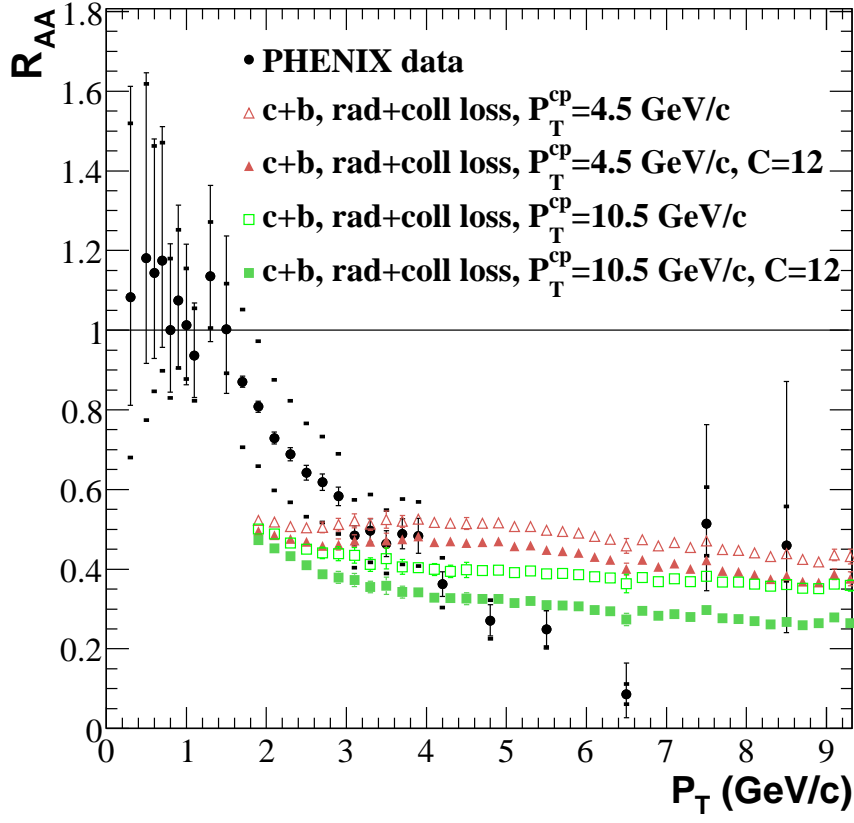


FIG. 5. Nuclear modification factor of non-photonic electrons (dots) measured in central (0–10%) Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV [5]. The symbols show the result of the simulation described in the text.